International Journal of Mechanical and Production
Engineering Research and Development (IJMPERD)
ISSN(P): 2249-6890; ISSN(E): 2249-8001
Vol. 4, Issue 4, Aug 2014, 15-22

A STUDY ON FLOW INDUCED VIBRATION EXCITATION IN SOLID SQUARE STRUCTURES

K. KARTHIK SELVAKUMAR & L. A. KUMARASWAMIDHAS
Department of Mechanical & Mining Machinery Engineering, Indian School of Mines, Dhanbad, Jharkhand, India

ABSTRACT

In order to study the fluid flow characteristics and the possibilities of suppressing the flow induced vibration excitation in elastically mounted solid square structures of aluminum and brass, an experimental analysis is performed at different conditions in an open type wind tunnel. The results observed from the present experimental study is compared and analyzed with the previous work. In the current study the blockage ratio were found to be 1.85% and 2.67% respectively. In turn, the observed oscillatory amplitude ratios of the test cylinders at different conditions is found to be minimum i.e. the maximum amplitude ratio(A/D) for the Al test cylinders is 0.225 and the maximum amplitude ratio (A/D) for the Brass cylinders is 0.25.

KEYWORDS: Flow Induced Vibration, Vortex Shedding, Vortex Induced Vibration

INTRODUCTION

When the bluff bodies are exposed to a steady and uniform flow, an interaction between the fluid and the structures will take place resulting into a fluctuating pressure force of considerable magnitude causing the Flow Induced Vibrations. Nowadays, the studies on the Flow Induced Vibration (FIV) have drastically increased in various fields of engineering and non-engineering applications. The vibrations induced by the fluid flow can be classified according to the nature of the fluid structure interaction, as shown in the following table 1

Table 1: Mechanism Causing Vibration by the Nature of Fluid Structure Interaction

Mechanism Causing Vibration			
1.	Additional Added Masses	8.	Galloping and Flutter
2.	Inertial Coupling Effect	9.	Induced Vibration due to Fluid Elastic Instability
3.	Instability Due to Parallel Flow	10.	Multi-Phase Buffeting
4.	Induced Vibration Due to Turbulence	11.	Acoustic Resonance
5.	Induced Vibration Due to Ocean Wave	12.	Hydraulic Transients
6.	Sonic Fatigue	13.	Environmental Excitation
7.	Induced Vibration Due to Vortex Shedding	14.	Transmitted Mechanical Vibration

In this paper it was symmetrically organized the important factors of flow induced vibration on the bluff bodies, particularly the studies on the fluid flow past the bluff bodies and Fluid structures interaction. The fluid-flows are broadly classified into internal, external and free shear flow. The present study is about the FIV due to the external flow of fluid over the bluff bodies i.e. circular, square or the rectangular cylinders. Basically interaction between the fluids and the structures were more complex phenomena to study. D. Shiels et al [19], found out that the FIV of an elastically constrained 2-D circular cylinder has become a significant problem in studying the interaction between the fluids and structures. Forthese type of problem L. Cheng, Y. Zhou [6], suggested the novel surface perturbation technique to control

fluid–structure interactions, including vortex streets, flow-induced vibrations and vortex-induced noise. From the view of various researchers, some possible sources for the FIV and its analyzing techniques are stated below. The FIV can be developed due to an alternating low-pressure, caused by the vortex shedding, behind a submerged cylinder, Hyun- Boo Lee, et al [9]. From the studies of M.J. Pettigrew et al [16], it was identified that the occurrences of vibration induced in the tube bundles by the cross flow, is mainly due to the fluid elastic instability. Ajith Kumar, R. Gowda, B.H.L [1], and Korkischko, I., Meneghini, J.R [12], suggested that the total number of cylinders and its arrangements was one of the parameters which have significant impact on the induced vibration due to fluid flow. H.S. Kang et al., [11], proposed an axial-flow-induced vibration model to evaluate the sensitivity to spring stiffness on the FIV of the bluff bodies. The important parameters of the heat exchangers to withstand the FIV are damping, mass per unit length, mass ratio, etc. which must be significantly evaluated at the stage of designing, H. Gelbe et al, [7]. Biswas and Ahamed [5], investigated the self-excited lateral vibration of a pipe due to an internal fluid flow and applied an integral minimum principle of Pontryagin, to find the optimum flow velocity for minimum pipe vibration (i.e.) to maximize the fluid transport efficiency, it is necessary to maximize the flow velocity while minimizing the lateral vibration of the pipe. L. Perotin and S. Granger [17], predicted that the dynamic behavior of the tube equipped with all the linear and non-linear supports, deduced from an identified turbulent excitation, provides a highly satisfactory validation for the regularized inverse identification process. Sang-Nyung Kim, and Yeon-Sik Cho [18], applied a mode frequency analysis, subroutine of Structural Routine in ANSYS, to carry out the analysis of the natural frequency and relative amplitude of the tube. B.A. Jubran et al., [10], applied the newly developed joint time-frequency analysis techniques (JTFA) and in particular, the modulated Gaussian wavelet to identify the characteristics of the FIV of an elastically mounted single cylinder subjected to the cross flow. Kumar, R.A. et al., [2], analyzed the flow-induced oscillations of a square section cylinder under interference conditions using a data-mining tool called 'decision tree'. Wu, W. et al., [20], investigated the high-frequency perturbation effects on the performance, to suppress the FIV in the bluff bodies. Baranyi, L., [3], proposed that the experimental methods and numerical analysis were much better, to study the near-wake structure of bluff bodies than the theoretical approach. The component failures due to excessive FIV, continue to affect the performance and reliability of the equipment's; such failures are very costly in terms of repairs which lead to loss of the production, Pettigrew, M.J., et al [11]. In order to study the fluid flow characteristics and the possibilities of suppressing the flow induced vibration excitation in elastically mounted solid square structures of aluminum and brass, an experimental analysis is performed at different conditions validated with the previous result is being discussed.

EXPERIMENTAL STUDY

The experimental investigations were performed in an open type low turbulence (0.1% turbulence intensity) wind tunnel at the Fluid Flow Laboratory of Indian School of Mines University (ISMU). The wind tunnel has test section of 0.3m x 0.3m x 1.0m, with a maximum wind speed up to 75 m/s. The temperature of the fluid flow was at 22°C. In turn, prior to the 9:1 contraction a layer of honeycomb and some screens were installed to reduce the turbulence. At the opening of the test section, a pitot tube was equipped to monitor the inlet fluid flow velocity. The flow velocity distribution without considering the boundary layer in the test section area is found to be even within 1.1%.

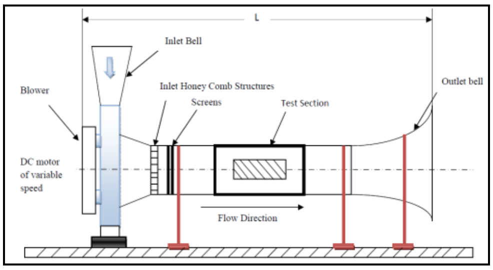


Figure 1: Experimental Set-up: Schematic Diagram of a Wind Tunnel

To visualize the fluid flow around the test cylinder surface, a smoke generator with a small orifice was placed at a half a diameter of the cylinder distance in the upstream condition. The orifice of the smoke generator was located at the mid-span of the cylinders and about the similar height of the cylinder axis in mid-span. In order to observe the vibration responses of the test cylinder, strain gauges were placed at point of contact where the cylinder is attached, which enables to monitor the force displacement and vibration response from the structures. The cylinder structures tested in the current study had different masses and dimensions, thus the mass ratios (m*) and mass-damping parameters (m*ξ) were represented as:

$$m^* = \frac{M}{m_d} = \frac{4M}{\rho \pi D_{mean}{}^2 L} \tag{1}$$

Where *(M)* represents the total oscillating mass, *(m_d)* the mass displaced, (ρ) density of air, (D_{mean}) outer diameter of the cylinder at its mid-span, (*L*) length of the cylinder and (ξ) structural damping coefficient. Figure 2 represent Schematic diagram of two cylinders arranged in side by side configuration. A summary of the tests carried out on different cylinders and the Comparative analysis of the current study with the previous studies were clearly represented in the table 2 and table 3. It provides the testing cylinder Identity, vibration directions examined, velocity, reduced velocity and the Reynolds number ranges in each test.

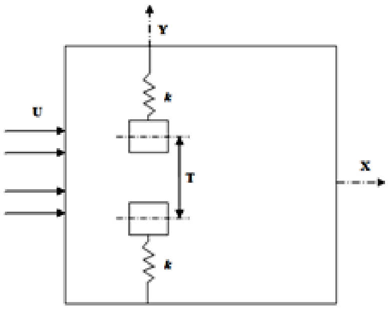


Figure 2: Schematic Diagram of Two Cylinders Arranged in Side by Side Configuration

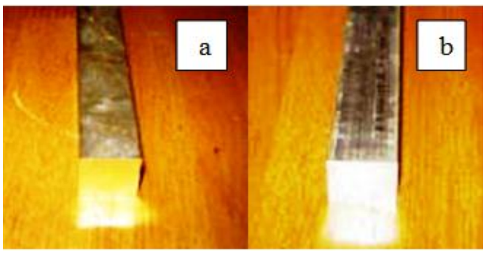


Figure 3: Test Specimens of (a) Brass, (b) Aluminum

Table 2: The Physical / Geometrical Properties of the Test Specimens

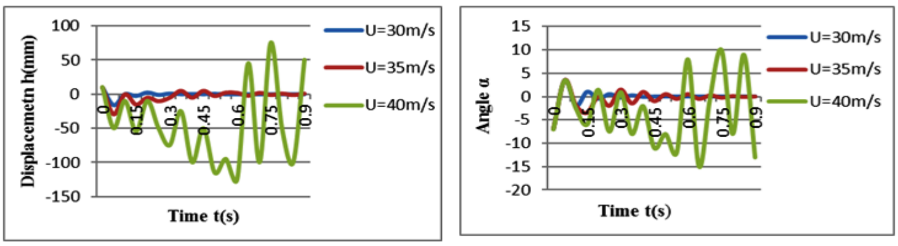
S.No	Test Cylinders Properties						
	Type	Cross Section (W x H) (mm)	Length L (mm)	Aspect Ratio (L/(W x H))	Weight (g)	Material	Cylinder Arrangement
1	Solid Square Cylinders	30 x 30	450	13.4	720	Aluminum	Side-by-side
2	Solid Square Cylinders	30 x 30	450	13.4	1350	Brass	Side-by-side

Table 3: Summary of the Tests Carried out on Square Cylinders

S.No	Structures	Vibration Direction	Velocity Range	Reynolds Number
1	Square Cylinder (Aluminum)	Cross – Flow	1-40 m/s	15000 - 64000
	Square Cylinder (Aluminum)	Stream – Wise	1-40 m/s	8600 - 58500
2	Square Cylinder (Brass)	Cross – Flow	1-40 m/s	14500 - 72000
	Square Cylinder (Brass)	Stream – Wise	1-40 m/s	7600 - 65500

RESULTS AND DISCUSSIONS

The responses of the square test cylinders made of aluminum and Brass were analyzed at different conditions, in which the Figures 4 and 5, shows vibration excitation characteristics of the cylinder structures. For a far field of flow velocity ($U_\infty \leq 35$m/s), the displacement (H) and the rotation angle α are dying in time. When U_∞ exceeds 30 m/s, then the damping of the flow-induced vibrations becomes weaker and at about U_∞ = 40 m/s the system becomes unstable by fluttering, the vibrations amplitudes become so high that it exceeds more than 100 mm and α=15° at a limit cycle oscillation shown in Figure 4.



(a) (b)

Figure 4: (a) & (b) Flow-Induced Vibrations Characteristics for the Velocity Range of, *u* = 30m/s, 35m/s, and 40 m/s

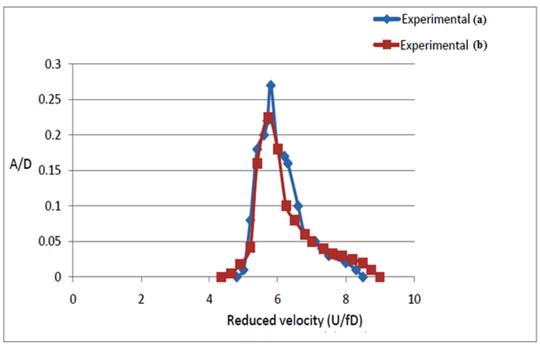


Figure 5: Oscillatory Amplitude vs. Reduced Velocity (a) Response of Al Test Cylinders, (b) Response of Brass Test Cylinders

The comparative analysis of the results of current study with the previous work is given in the table 4.

Table 4: Comparative Analysis of the Current Study with the Previous Results

S. No	Ref	Wind Tunnel	Test Section		Material	Velocity (m/s)	Turbulent Intensity %	Blockage Ratio	A/D
			Cross Section (W x H)	***Length (L)***					
1	[10]	Open Type	300mm x 300mm	2000mm	Aluminum	4- 27	0.35	-	-
2	[15]	Open Type	300mm x 300mm	1200mm	Styrofoam	1- 30	0.5	-	-
3	[8]	Closed Circuit	600 mm x 600 mm	2000mm	-	4 – 30	0.4 & 0.5	13.8	-
4	[13]	Closed Circuit	600 mm x 600 mm	2300mm	NACA0012 airfoil	5.48	0.025	-	-
5	[14]	Open Type	350mm x 350mm	2000mm	Brass	14	0.5	7.1	-
6	Current Study	Open Type	300mm x 300mm	2000mm	Aluminum	1- 40	0.45	1.85	0.225
		Open Type	300mm x 300mm	2000mm	Brass	1- 40	0.48	2.67	0.25

In order to attain a standard smooth flow configuration, the turbulence intensity (I) must be around 0.3% to 0.5% for different velocity ranges [8], in the current study the Turbulent Intensity for the solid square structures are found to be 0.45% and 0.48% respectively. In turn, the blockage has a very significant impact on the response of the bluff bodies undergoing vortex-induced vibrations. Where, the blockage ratio greater than 2.5% lead to the hysteresis in the fluid flow and response of the bluff bodies at the onset of synchronization, where higher blockage ratio also leads to an error in the whole process. In the current study the blockage ratio were found to be 1.85% and 2.67% respectively. In turn, the observed oscillatory amplitude ratios of the test cylinders at different conditions were presented in the figure 5, which is found to be minimum (i.e.) the maximum amplitude ratio(A/D) for the Al test cylinders is 0.225 and the maximum amplitude ratio (A/D) for the Brass cylinders is 0.25.

RECOMMENDATION FOR THE SUPPRESSION OF FLOW INDUCED VIBRATION

The important issues that must be taken into the consideration for the suppression of FIV in the bluff bodies are,

- It is possible to suppress both the structural vibration and the wake vortex on the bluff bodies by introducing a perturbation input at a high-frequency range, well-exceeding the resonant frequency of structure.
- Attaching the tripping wires in the leading stagnation line of the bluff bodies can suppress the vibration.
- Better prediction of VIV would hopefully lead to a better suppression of vibration.
- From the studies it was found that the helical strakes can be used successfully in wind engineering to suppress the VIV in chimneys and other slender structures.
- Introduction of fins was found to reduce the strength of vortex shedding slightly, in turn strongly reducing the radiated sound before the onset and during the lock-in range of the acoustic resonance.

ACKNOWLEDGEMENTS

Authors gratefully acknowledge the support of research grant (No.SB/FTP/ETA-389/2012) awarded by the Department of Science and Technology (DST), Government of India.

REFERENCES

1. Ajith Kumar, R., Gowda, B.H.L., 2006. Flow-induced vibration of a square cylinder without and with interference, Journal of Fluids and Structures, 22, 345–369.
2. Ajith Kumar, R., Sugumaran, V., Gowda, B.H.L., Sohn, C.H., 2008. Decision tree: A very useful tool in analyzing flow-induced vibration data, Mechanical Systems and Signal Processing, 22, 202–216.
3. Baranyi, .L., 2008. Numerical simulation of flow around an orbiting cylinder at different ellipticity values, Journal of Fluids and Structures, 24, 883–906.
4. Belvin, R.D, 1990. Flow –Induced Vibration, second ed. Van Nostrand Reinhold, New York.
5. Biswas, Saroj K., Ahmed, N. U., 2001. Optimal Control of Flow-Induced Vibration of Pipeline, Dynamics and Control, 11, 187–201.
6. Cheng, L., Zhou, Y., 2008. Surface perturbation technique for flow-induced vibration and noise control, Journal of Sound and Vibration, 310, 527–540.
7. Gelbe, H., Jahr, M., Schroder, K., 1995. Flow-induced vibrations in heat exchanger tube bundles, Chemical Engineering and Processing, 34, 289-298.
8. Hemon, P., Santi, F., Schnoerringer, B., Wojciechowski, J., 2001. Influence of free-stream turbulence on the movement-induced vibrations of an elongated rectangular cylinder in cross-flow, Journal of Wind Engineering and Industrial Aerodynamics, 89, 1383–1395.
9. Hyun-Boo Lee, Tae-Rin Lee, Yoon-Suk Chang, 2013. “Numerical simulation of flow-induced bidirectional oscillations” Journal of Fluids and Structures, 37, 220–231.
10. Jubran, B. A., Hamdan, M. N., Shabaneh, N. H., 1998. Wavelet and chaos analysis of flow induced vibration of a single cylinder in cross- flow, International Journal of Engineering Science, 36, 843±864.
11. Kang, H.S., Song, K.N., Kim, H.K., Yoon, K.H., 2003. Axial-flow-induced vibration for a rod supported by translational springs at both ends, Nuclear Engineering and Design, 220, 83-90.
12. Korkischko, I., Meneghini, J.R., 2010. Experimental investigation of flow-induced vibration on isolated and tandem circular cylinders fitted with strakes. Journal of Fluids and Structures, 26, 611–625.
13. Lau, Y.L., So, R.M.C., Leung, R.C.K., 2004. Flow-induced vibration of elastic slender structures in a cylinder wake, Journal of Fluids and Structures, 19, 1061–1083.
14. Mahbub Alam, Md., Zhou, Y., 2008. Strouhal numbers, forces and flow structures around two tandem cylinders of different diameters, Journal of Fluids and Structures, 24, 505–526.

15. Okajima, A., Nagamori, T., Matsunaga, F., Kiwata, T., 1999. Some Experiments on flow-induced Vibration of a circular cylinder with Surface roughness, Journal of Fluids and Structures, 13, 853-864.

16. Pettigrew, M.J., Taylor, C.E., Fisher, N.J., Yetisir, M., W. Smith B.A. 1998. Flow-induced vibration: recent findings and open questions, Nuclear Engineering and Design, 185, 249±276.

17. Perotin, L., Granger, S., 1999. An Inverse Method For The Identification Of A Distributed Random Excitation Acting On A Vibrating Structure Part 2: Flow-Induced Vibration Application, Mechanical Systems and Signal Processing, 13 (1), 67-81.

18. Sang-Nyung Kim, Yeon-Sik Cho, 2004. The Analysis of Flow-Induced Vibration and Design Improvement in KSNP Steam Generators of UCN #5, 6, KSME International Journal, 18(1), 74 - 81.

19. Shiels, D., Leonard, A., Roshko, A., 2001. Flow-Induced Vibration of a Circular Cylinder at Limiting Structural Parameters, Journal of Fluids and Structures, 15, 3-21.

20. Wu, W., Yuan, J., Cheng, L., 2007. Multi-high-frequency Perturbation effects on flow-induced vibration control, Journal of Sound and Vibration, 305, 226–242.